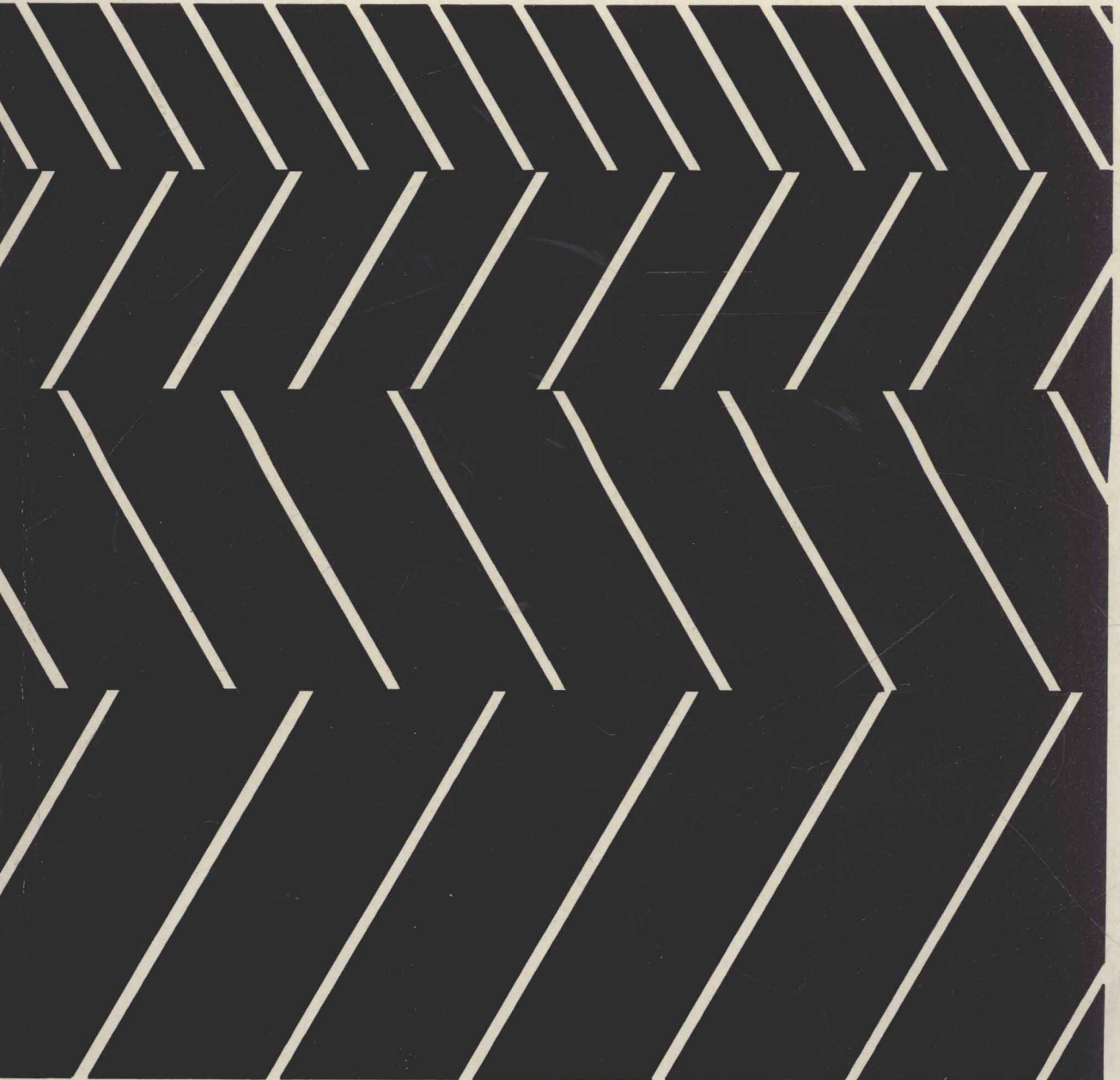# The Soil

An introduction to soil study
Second Edition

F. M. Courtney and S. T. Trudgill

The Soil

An introduction to soil study

F M Courtney M.Sc., Cert. Ed.

Education Officer, Avon County Council

S T Trudgill Ph.D.

Lecturer in Geography, University of Sheffield

Preface

Soil is a resource used by man and is a component of environmental systems. Thus it can be studied in terms of links between soil properties and process and other environmental components such as air, water, rock and life. In addition, the soil properties and processes which affect the use of soils by man are important topics for study. It is intended that this book should provide an introduction to these topics for the upper secondary levels of education and for introductory levels of higher education (colleges, universities and polytechnics). It is also intended for teachers who may already be specialists in other areas but who are relative newcomers to soil study. The book covers basic soil study and will therefore be useful to soil scientists, geographers, geologists, biologists, agriculturalists, ecologists and environmental scientists.

In this Second Edition we have taken the opportunity to broaden the scope of the book to make it applicable to various parts of the world. World soils is an extremely large topic and so the treatment of examples is necessarily selective. The examples selected are aimed at emphasising the major soil resources in the northern temperate lands, especially the more fertile glacial drifts and other soils used for arable cultivation, together with the deeply weathered tropical soils which form the basic resource of much of the more densely populated tropical areas. In addition, the problems of soil salinity are also discussed as they limit much of the potential use of soils in arid areas. The treatment of the principles of soil formation and properties is, however, aimed at covering many aspects applicable to world soils outside these more detailed case studies.

Chapter one deals with the fundamental processes involved in the development of soil. Chapter two examines the components of soil, their properties and the way in which these may combine to influence overall soil properties. In Chapter three, individual soil types are discussed. Chapter four discusses soil as a component of the ecosystem, dealing with the circulation and flow of nutrients, water and energy and with soil-plant relationships. Chapter five considers soil management and the evaluation of soil resources, Chapter six deals with the description and mapping of soil in the field and Chapter seven with a discussion of soil classification.

World soil classification is a confusing topic for the beginner: there are several different classifications in existence, often with different schemes in different countries. Moreover, it is often difficult to equate the terms of newer classifications with those of older ones. In this book, both older, established terms and soil classifications and the newer scheme of the United States Department of Agriculture (USDA) are covered in broad terms, using equivalent terms from other major classifications with cross-referencing to established older classifications where possible. Thus, the book provides an introduction to the principle soil groups and their major classifications; further details are discussed for selected areas only.

The book therefore attempts to impart the basic ideas of soil study, especially of components, interactions, processes, resources, description and classification. This will prepare the reader for more advanced texts where some of the complexities of interactions and classifications will be more apparent.

Frank Courtney
Stephen Trudgill

Contents

1

Soil development

1.1 Rock and soil

Rock weathering

Soil develops when rock at the surface of the earth is changed by a series of processes, collectively known by the term *weathering*. The rock is weathered and broken down by the combined action of water, gases and living matter. The formation of soil is not just a matter of the disintegration of rock; while the rock is disintegrating it is exchanging material with its immediate environment. A true soil is therefore a rock which has exchanged some material with its environment and the soil now incorporates not only rock but also water, gases and both living and dead organic matter.

Rocks and equilibrium

When rock breaks down to form soil it is tending to come into *a state of equilibrium* with its environment. By using the phrase 'a state of equilibrium' it is meant that an object is adjusted to the external forces acting upon it.

For example, if you were to place a beaker of hot water in a cold room then the water would cool until it was the same temperature as the room. The water would at that stage be adjusted to its external environment and would be in a state of equilibrium with the temperature in the room. Similarly one litre of hot water mixed with one litre of cold water would mix to produce two litres of warm water. In this case both items have adjusted to each other, resulting in a compromise.

The principle of equilibrium can be stated in a more general way:

matter tends to change by the loss or gain of energy into a form where energy differences between the matter and its environment (or between two sets of matter) are minimized.

Rock material deep inside the earth's crust is molten. This is an adjustment to the forces acting on the material. Nearer the earth's surface, rock is cooler and more crystalline. This is also an equilibrium adjustment to conditions.

Eventually, by earth movements or the erosion of the overlying rock, the piece of rock may find itself at the surface of the earth. The rock will have inherited characteristics from the place of its origin in the earth's crust, but it is now in a new environment at the surface. It is in *disequilibrium* with the new environment. That is, it is not in equilibrium with the conditions at the surface of the earth where cooler (and changeable) temperatures occur and where water, air and organisms are present. The rock has to adjust to the new conditions.

The adjustment can take many forms and may vary in the amount of time it takes, according to the nature of the surface conditions. In desert conditions the simple disintegration of rock occurs. The production of sand can be viewed as an equilibrium adjustment to harsh conditions. The rock cannot withstand the expansion and contraction caused by temperature changes, but the sand can expand and contract freely. Soil is not formed, however, because there is insufficient water and life to be incorporated into the disintegrated rock.

The material that disintegrates to produce the soil is called the *parent material*. It may be *igneous* rock, which had its source deep in the earth's crust as described above. It may be a *sedimentary* rock which has been formed from the deposition of previously weathered rock. Although these rocks have not been as deep in the earth's crust as igneous rocks and so have not become molten, they still inherit characteristics from the place where they were first deposited, for example in a fresh water or marine basin. As soon as they reach the surface of the earth they will start to alter, in response to the new conditions they have met. The third group of rocks are the *metamorphic* rocks, which are sedimentary rocks altered by heat or pressure. Also many soils in Britain are developed on *unconsolidated deposits* such as river alluvium or glacial drift. Again these deposits inherit characteristics from having been laid down under water or ice and when exposed at the surface begin to adjust to surface

conditions and incorporate rain water, gases, organisms and organic matter to form soil.

The soil system

The approach adopted by systems analysis is extremely useful in the study of soil development. The object under study is termed the *system* and the workings of the system are divided into *inputs, outputs* and *internal processes*. Using this approach a soil can be studied in a similar way to a processing factory with raw material input, internal manufacturing processes and the output from the system (Figure 1).

In the case of the soil system, the system under study is the soil between the living plant above and the unaltered parent material below, whether this be igneous or sedimentary rock or an unconsolidated deposit. The inputs and outputs of a small area of soil (Figure 2) can be listed:

Inputs
1 Nutrients from decaying rock. (Nutrients are the chemicals used as plant food.)
2 Water from the atmosphere.
3 Gases from the atmosphere and the respiration of soil animals.
4 Solar energy. This provides energy to plants, thus controlling inputs in 5 and 6.
5 Organic matter from decaying vegetation and animals.
6 Excretions from plant roots.

Outputs
1 Nutrients taken up by plants.
2 Nutrient losses into water passing through the soil.
3 Losses of soil material by soil creep downslope. These may, of course, then form inputs to areas of soil downslope.
4 Evaporation.

However, the soil system is not a simple matter of input and output, and under natural conditions *recycling* will occur. For example, the nutrients lost as an output (output 1) may well return in leaf litter the following autumn (input 4). In this way many nutrients are recycled through the system. Obviously if the vegetation is removed by a crop the nutrient store of the soil will gradually be depleted until fertilizers will have to be added to the soil to replace them.

Movement in the system

The movement of *water* in the soil governs most of the processes in the soil. It governs the removal of

nutrients in drainage waters and the biological processes within the soil. It influences most of the *internal processes* of the soil, whether they be chemical, physical or biological.

Within soil, nutrients can be moved from their original positions, transported through the soil and deposited higher or lower in the profile (or vertical soil section). If the dominant water movement in the soil is downwards, as in regions of high rainfall and where the soil is very porous, the nutrients will be transported downwards in the profile. The loss of nutrients from the upper part of the soil downwards is referred to as *leaching*. The transport and deposition of various soil constituents to different depths in the soil leads to the formation of horizontal layers within the soil. These are termed soil *horizons* and can often be distinguished as differently coloured layers in a section dug through soil in a pit or roadside cutting. Further details of soil horizon distinctions are given in Chapter six and section 3.1.

1.2 Agents and processes of rock weathering and soil development

We have seen that soil is formed by the interaction of the soil parent material with its environment. But how does a parent material incorporate water, gases and organic material from the environment to form soil? This section looks at the processes which enable the equilibrium adjustments of parent material to take place. The soil-forming processes that result from the exposure of the material to water, air and life are considered in turn.

Processes associated with exposure to water

The most important process is that of dissolving. Associated processes are those of *hydrolysis* (the break down of minerals by water) and *hydration* (the incorporation of water into the mineral structure).

DISSOLVING
Materials *dissolve* into water to form a *solution* of the material. Dissolving (the verb to dissolve) is the process, and the solution (the noun) is the resultant product.

Before we can understand how solution processes work in the soil it is necessary to refer to a knowledge of basic chemistry. When a soluble material (the *solute*) comes into contact with water (the *solvent*) small particles of the solute move out from the solid into the water. This is the process
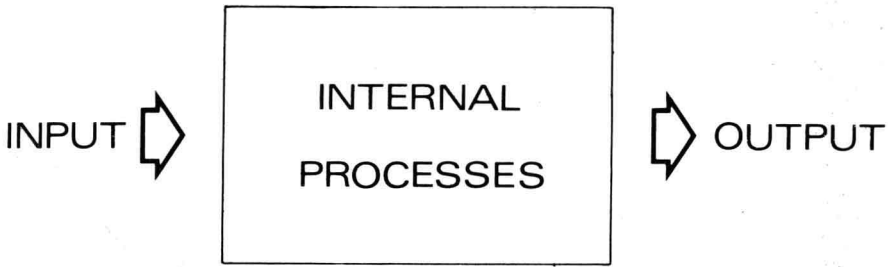
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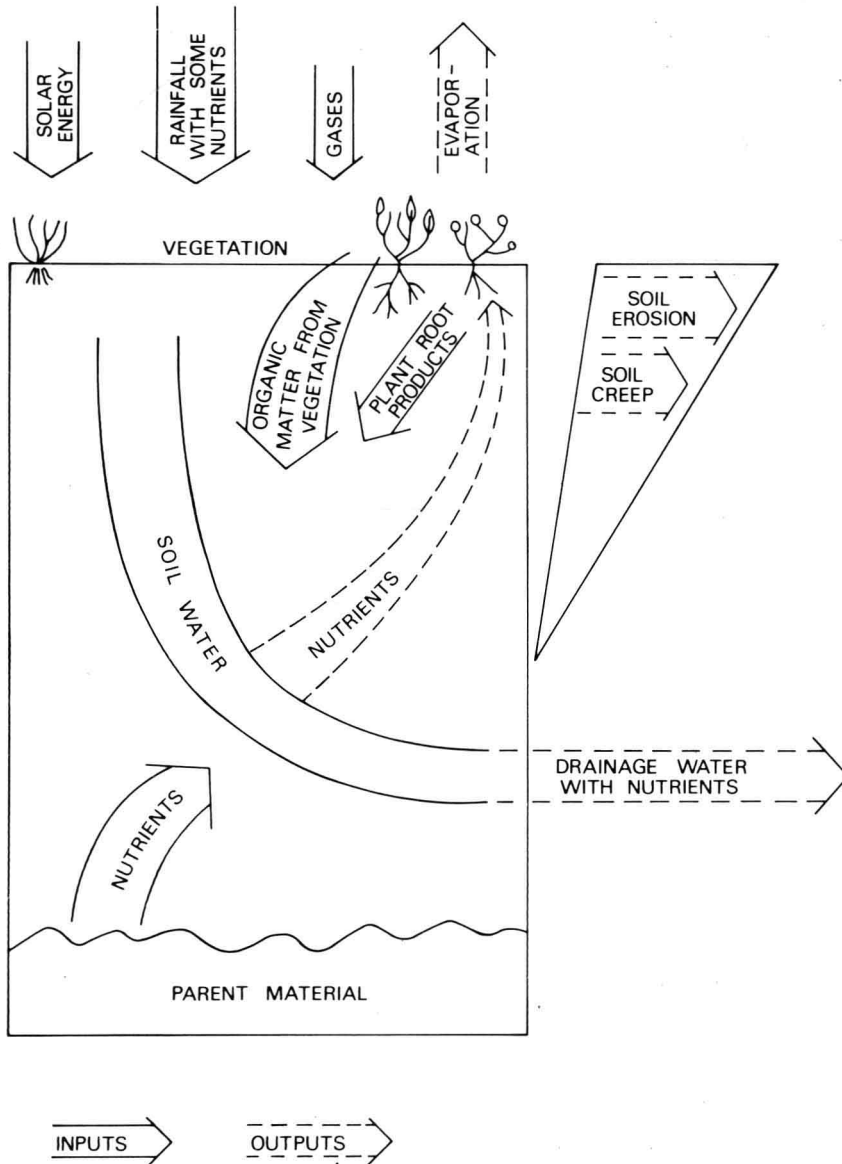**Figure 1**   The basic systems approach

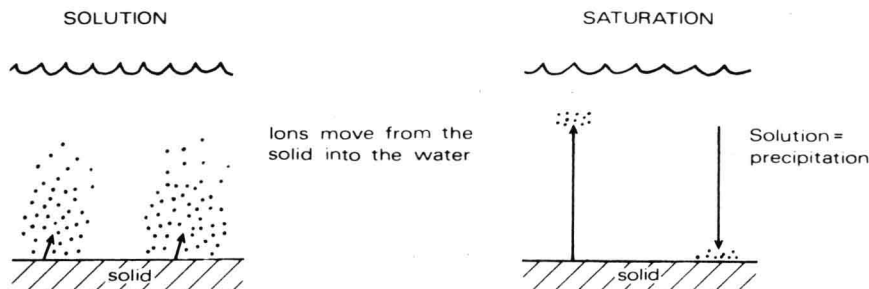**Figure 2** · The major soil inputs and outputs

3

Figure 3 The process of dissolving

of simple *dissolving* (Figure 3). When many solutes dissolve they split up (or *dissociate*) into their constituent parts (though not all substances dissociate when dissolved and can exist as compound molecules in solution). These constituents are electrically charged and are referred to as *ions*. Common salt, for instance (sodium chloride), dissociates in water to yield separate sodium and chloride ions:

$$NaCl \longrightarrow Na^+ \text{ and } Cl^-.$$
$$\text{cation} \qquad \text{anion}$$
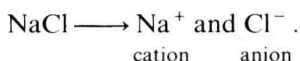
Sodium chloride in bulk is electrically neutral but dissociates to give *positively charged* sodium *cations* and *negatively charged* chloride *anions*.

Solute ions can also move back from the water to the solid and this is the process of chemical *precipitation*. Obviously, while the solid is dissolving the net movement of ions will be from the solid to the water. But at a certain stage it will be found that as many ions are moving from the water to the solid as are moving in the opposite direction. That is, **precipitation equals dissolution. A state of equilibrium has now been reached**; this is called *saturation*. The concentration of solute ions in the water at the equilibrium saturation state defines the *solubility* of the solute. Figure 4 demonstrates the amounts of various chemical elements found in soil water.

This basic chemical knowledge of the solution process can now be applied to the soil-forming situation. The constituents of the soil parent material will each possess a different solubility. The more soluble constituents will be easily washed away by rainwater and the least soluble will remain as the framework or skeleton of the soil. The formation of soil horizons, mentioned in section 1.1, is influenced largely by the solubility of soil materials. The more soluble chemicals are carried further down the soil profile while the least soluble chemicals remain undissolved in the upper layers of the
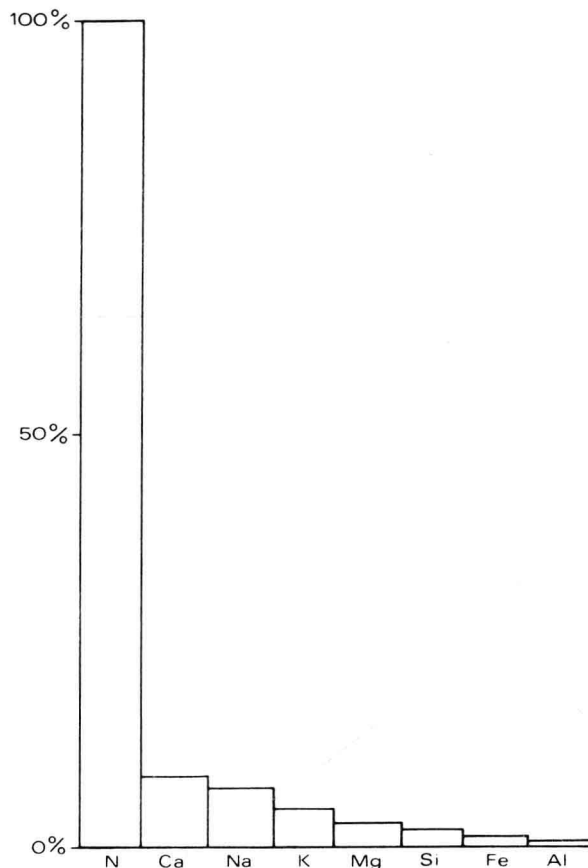

Figure 4 Relative amounts of chemical elements found dissolved in water from a mineral soil (expressed as a percentage of the amount of N). *Note:* Percentages are only approximate

soil. Rain water percolates through the upper layers of the soil, dissolving material slowly. Eventually the state of saturation will be reached and no further material can be dissolved. The materials are

4

then redeposited, or precipitated, lower down the soil profile (Figure 5).

It can be seen that the process of solution is an important way in which the minerals of the parent material of the soil react to the presence of water. Therefore the solubility of the soil parent material and the amount of rainfall (solvent) are important factors in the formation of soil, and an insoluble material will not break down easily to form soil, however much rain falls on it. Soluble material on the other hand will be readily moved in wetter areas, the degree of movement down the soil profile depending upon the amount of rainfall input to the soil.
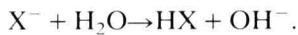
HYDROLYSIS

Hydrolysis is the breaking down of minerals (in the parent material) by hydrogen ions and hydroxyl ions derived from water. Thus the mineral *combines* with the water rather than simply dissolving in it by dissociation. Some water in the soil exists in a partly dissociated state, that is the H_2O is already partly split up into H^+ and OH^- ions and the hydrogen ion (H^+) is particularly important in the attack of minerals.

In solutions of pure chemicals in the laboratory both H^+ and OH^- ions are involved in hydrolysis. For cations (M^+) the equation is:
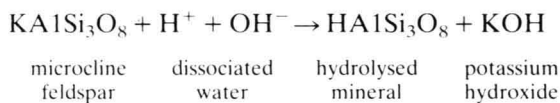
$$M^+ + H_2O \rightarrow MOH + H^+.$$
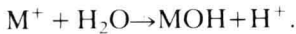
For anions (X^-) the reaction is:

$$X^- + H_2O \rightarrow HX + OH^-.$$

Hydrolysis is thus the reaction of a solid ion with water to form an associated iron species plus H^+ or OH^-.

In natural situations complex minerals exist and hydrolysis is not as simple as in the above equations. Often both cation hydrolysis and anion hydrolysis occur together. Frequently cations in a mineral combine with OH^- ions from water and then the cations are replaced by H^+ ions later. An example of a complex reaction is that of microcline feldspar reacting with water.

$$KAlSi_3O_8 + H^+ + OH^- \rightarrow HAlSi_3O_8 + KOH$$

| microcline feldspar | dissociated water | hydrolysed mineral | potassium hydroxide |

The hydrolysed mineral containing the H^+ ion is unstable and usually breaks down.

Minerals composed of weakly ionised cations combine with OH^- of water more than with H^+ ions. Minerals composed of weakly ionised an-

a. Relatively insoluble elements

b. Moderately soluble elements

c. Very soluble elements
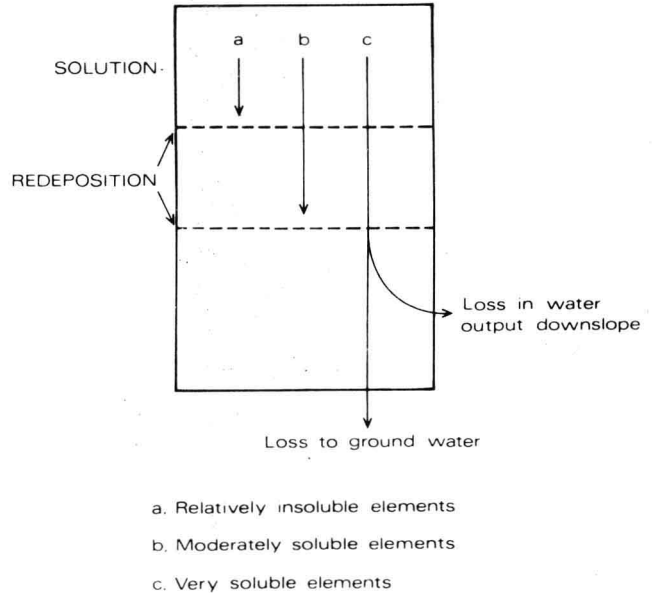
Figure 5 Solution and redeposition in the soil profile

ions, such as the silica-rich minerals, take up H^+ ions from the water more than the OH^- ions.

An important factor in natural processes is that pure water rarely exists because it is usually dominated by hydrogen ions, H^+. These are derived from organic acids from decaying humus and the dissociation of carbonic acid in water:

$$CO_2 + H_2O \rightarrow \underset{\substack{\text{carbonic} \\ \text{acid}}}{H_2CO_3} \rightarrow H^+ + HCO_3^-$$

Plant roots and exchangeable hydrogen ions on acid clays also supply hydrogen ions. Thus in soil water containing much organic matter and many plant roots and acid clays the hydrogen ion tends to be the most important factor, leading to the dominance of mineral anion hydrolysis.

Many minerals that make up igneous and metamorphic rocks are rich in silica (SiO_2). The atoms in many silicate minerals are arranged in pyramids (called silica *tetrahedra*). These tetrahedra are held together by other atoms, especially calcium (Ca) or magnesium (Mg). The hydroxyl and hydrogen ions from water attack these atoms that link the tetrahedra and replace them with hydrogen ions. The silica tetrahedra which are linked by hydrogen ions are unstable and soon break apart. Thus the silicate minerals break down under attack from water which renders the minerals unstable (Figure 6).

5

Silica tetrahedra

Side view   Front view

Note: the side view and front view are symmetrical

Water H_2O
H^+ OH^-
2 silica tetrahedra held together by magnesium (Mg)

H^+
Mg
+
OH^-
Mineral absorbs hydrogen ion (H^+). Mineral cation (Mg^{++}) combines with hydroxyl ion (OH^-)

H^+
Break down of tetrahedra bond and formation of new hydrolysed mineral.

Mg^{++} and OH^- combine in solution
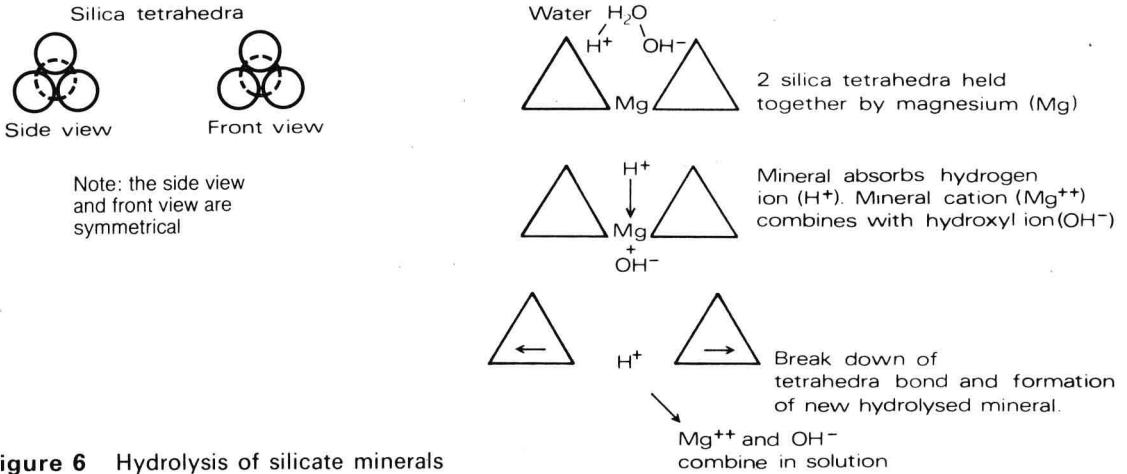
Figure 6   Hydrolysis of silicate minerals

Note.— Quartz is very resistant to attack, but Olivine readily takes up hydrogen ions

pH 10

ALKALINE (low in hydrogen ions) 9

OLIVINE – rapid uptake of hydrogen ions

8

HORNBLENDE – gradual uptake of hydrogen ions

NEUTRAL 7

6

5

ACID (high in hydrogen ions) 4

QUARTZ – not attacked by hydrogen ions

3

0   1   2   3   4   5   6   7
Time (minutes)
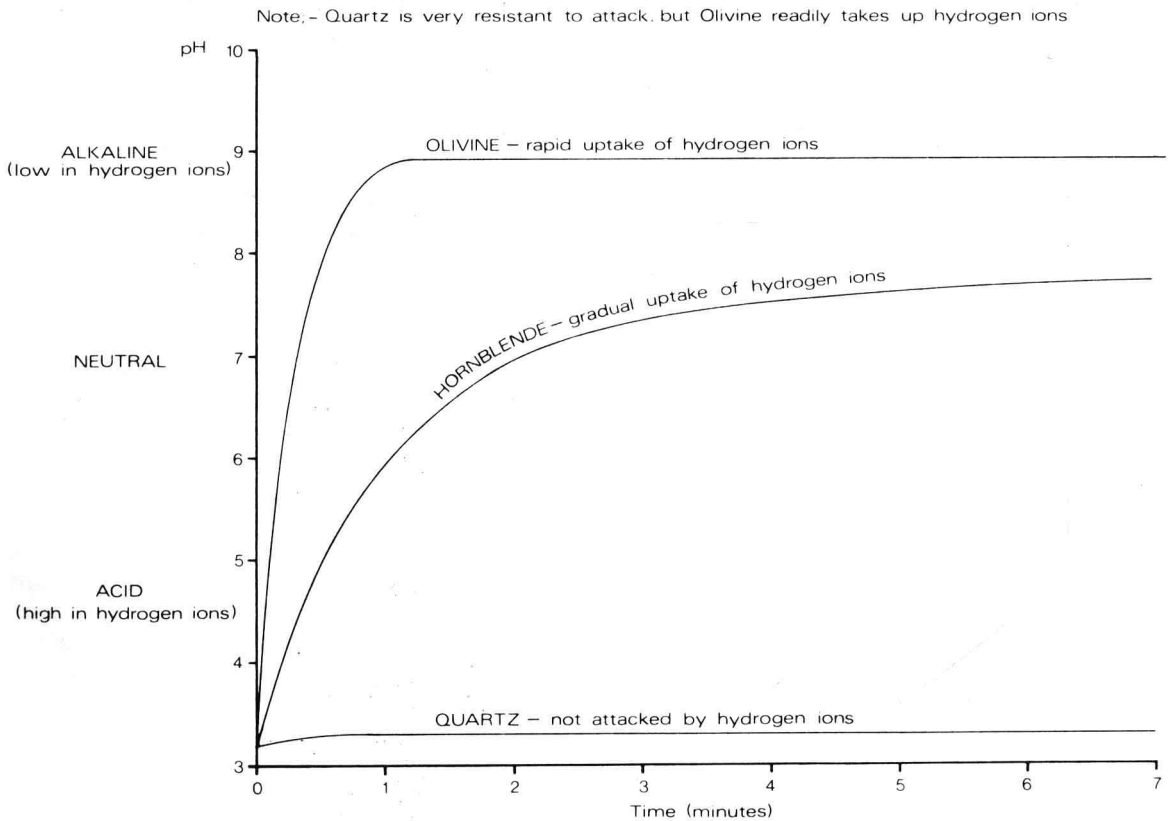
Figure 7   Hydrolysis: the uptake of hydrogen ions by three minerals: olivine, hornblende and quartz

It is possible to watch the process of hydrolysis occurring in a laboratory. If a silicate mineral is ground down to a fine powder and placed in water rich in hydrogen ions it is possible to measure the decrease in the amount of hydrogen ions in the water as they are absorbed into the mineral and caused the silica tetrahedra to break up. The concentration of hydrogen ions in water can be expressed in moles per litre hydrogen ions. A mole is the molecular weight in grams; for hydro-

6

gen this is 1, so 1 mole per litre = 1 gram per litre. Hydrogen ion concentration is often written thus: $[H^+]$, the square brackets indicating concentration. At neutrality there are $0.0000001\,g\,l^{-1}$ hydrogen ions; since this is a cumbersome number, the logarithmic transformation, pH, is used. pH is thus defined as the logarithm of the reciprocal of the hydrogen ion concentration:

$$pH = \log \frac{1}{[H^+]}$$

The pH value of $0.0000001\,g\,l^{-1}$ $[H^+]$ is 7 and thus this concentration is equal to pH 7. pH 7 is neutral when H^+ ions are balanced by OH^- (hydroxyl) ions, values above this are alkaline and below this are acid. Using a pH meter or pH papers it is possible to detect a pH change from acid to alkaline as silicate minerals react with water and take up hydrogen ions (see Figure 7 and section 2.11).

HYDRATION

Some minerals can react to the presence of water by incorporating it directly into their crystal structure. The mineral anhydrite ($CaSO_4$), for instance, although not common in British soils, can occur in tropical soils and may be used to illustrate the process of hydration.

Anhydrite takes up water to form gypsum ($CaSO_4.H_2O$):

$$CaSO_4 + H_2O \rightarrow CaSO_4.H_2O.$$
anhydrite   water   gypsum
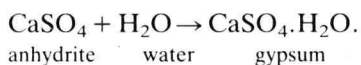
The uptake of water can alter the solubility of the minerals. In this example gypsum dissolves far more rapidly than anhydrite, taking fifteen days to reach saturation, whereas anhydrite takes thirty days to reach saturation.

Climate

While the nature of the parent material will be important in soil formation, the climatic conditions prevailing during soil formation will be equally important. In cold climates, the occurrence of freeze-thaw cycles will be important in the breakdown of rock masses. This breakdown provides a large number of surfaces for chemical processes to act upon. In hotter climates, thermal expansion and contraction of rock may have a similar effect. The amount of rainfall, or other source of moisture, such as dew, will also be an important consideration. Freezing and thawing of wet rock is a more effective process of rock shattering than is the freezing and thawing of drier rock. Similarly, thermal expansion and contraction of moist rock appears to be more efficient at breaking down rocks than is the expansion and contraction of dry rock. In addition, the movement of water through weathered rock masses and soil materials removes chemical weathering products in solution. In temperature and tropical climates the dominant movement of water is downwards. Weathering products are therefore moved downwards through the soil and rock material in solution, a process known as *leaching*. In semi-arid areas, the net direction of water movement often tends to be upwards because evaporation exceeds precipitation when measured on an annual basis. Here salts tend to be transported upwards through the soil and rock material, accumulating towards the surface and limiting the extent of chemical weathering. This process is known as *salinisation*.
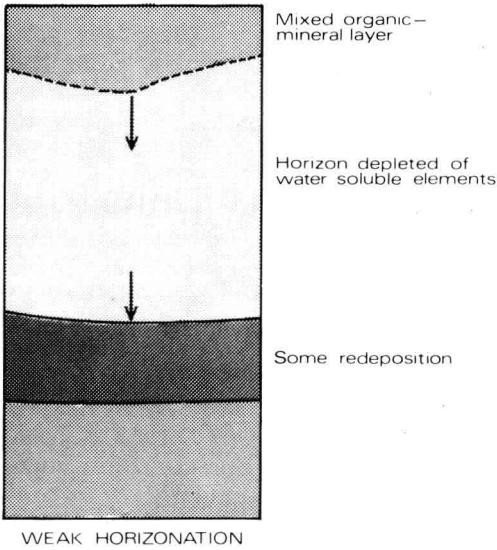
Climates have often changed in the past, notably during the Pleistocene glaciations. During the glaciations, temperate latitude experienced a colder, more glacial climate than at present, with extensive ice sheets, while other mid-latitude areas, now arid or semi-arid, experienced a wetter climate. These legacies of climatic change have had a profound effect on soil formation and it is impossible to understand the nature and distribution of present soil resources without taking climatic change into account. In temperate latitudes, many of the deeper agricultural soils are developed from deposits of glacial drift. Evidence of disturbance by periglacial action is often seen – frost heaving and accumulation of soil material at the bases of slopes are notable examples. In currently drier climates, many of the soils can be thought of as developing during past, wetter periods, with less soil development at the present day. Many areas which are presently covered in saline soils were once areas occupied by former lake beds, the lakes having dried up during climatic change following the Pleistocene.

Temperature regime and moisture regime are thus two important factors in the weathering of rocks and in soil development; it should be emphasised, however, that because of climatic changes, not only current but also past climatic regimes have to be considered in order to gain a full understanding of the nature and distribution of current soil resources.

Processes associated with exposure to air

The most important process is that of oxidation.

7

A) Simple leaching

Mixed organic—
mineral layer

Horizon depleted of
water soluble elements

Some redeposition

WEAK HORIZONATION

B) Cheluviation — leaching with chelates

Organic layer
supplies chelates

Bleached horizon

Chelation of soil
elements (especially
Fe and Al)

Redeposition

STRONG HORIZONATION
—very distinct horizons

Figure 8   Leaching and cheluviation

60%

Amount in
water for
comparison

0%

Na   Mg   Si   Fe   Al
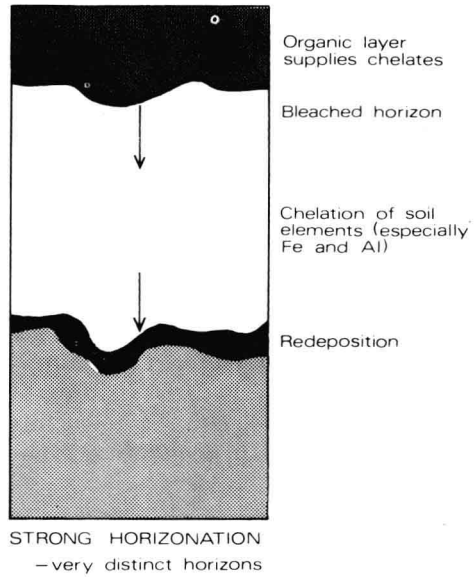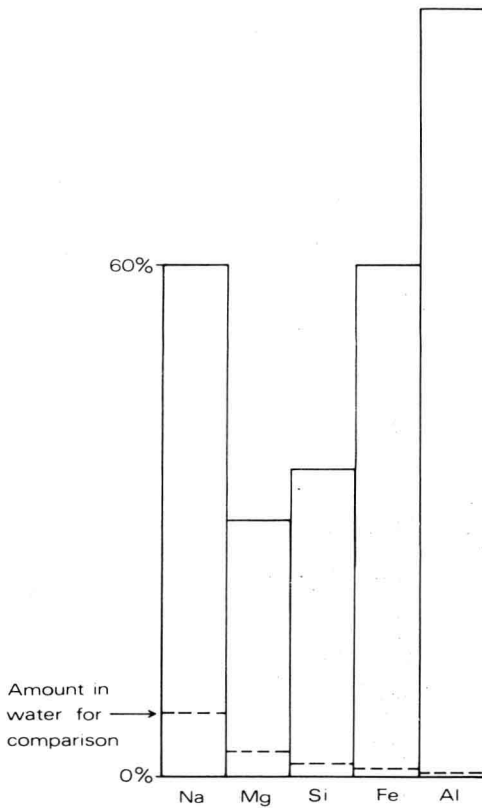
Figure 9   Relative amounts of chemical elements
dissolved in water from soil rich in organic
acids (vertical axis as in Figure 4). *Note:*
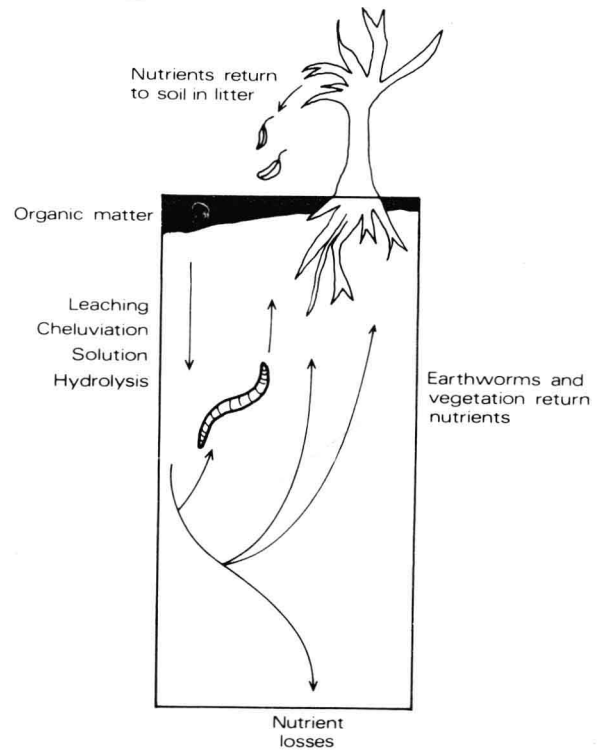Percentages are only approximate

Nutrients return
to soil in litter

Organic matter

Leaching
Cheluviation
Solution
Hydrolysis

Earthworms and
vegetation return
nutrients

Nutrient
losses

Figure 10   Nutrient movement in soil

8

Minerals in the soil parent material may take up oxygen from the atmosphere. This is a spontaneous reaction as the minerals are unstable in the presence of oxygen. Thus, when exposed to the air they spontaneously oxidize to achieve a chemically more stable form. This is, therefore, a good example of a mineral reacting to its new environment at the surface of the earth. Oxidation occurs as the mineral attempts to come into a state of equilibrium with its environment.

The characteristic brownish or reddish colours of most soils are due to the presence of oxidized iron. Ferrous iron (Iron II compounds) can be oxidized to ferric iron (Iron III compounds) which is red. In waterlogged soils, where air cannot easily penetrate, the soil is bluish or greenish. Here the colour comes from the unoxidized ferrous iron which is characteristically blue-green. Red mottles can be seen in some waterlogged soils where air has been able to penetrate (e.g. down old root channels) and oxidize the iron (see section 3.1).

Ferrous iron (Iron II) is much more soluble than ferric iron (Iron III) and because the former is present in waterlogged soils, iron is highly mobile under wet conditions. Iron may be precipitated, however, by contact with air or by changes in pH where acid waters lose their acidity. Iron may also be reduced and mobilised by organic compounds (see section 3.1). Iron may thus be mobile in wet, organic soils but be present in the insoluble ferric (Iron III) form under oxidising conditions. Insoluble iron oxide (Iron III compounds) often dominate tropical soils which have been strongly weathered under oxidising conditions for long periods of time. Such soils are to be found on very old land surfaces in parts of Australia, central Africa, South America, and parts of India and South East Asia. These soils are coloured red from the dominance of oxidised iron and various names have been given to these soils including oxisols, ferruginous soils and ferralitic soils (see Chapter 3).

Processes associated with exposure to plants and animals

The presence of life is critical to the formation of a true soil. If the environmental conditions are not suitable for plant and animal growth a true soil will not be formed. Plants and animals have two important functions in the soil formation processes:

1 They provide organic matter (through decay) which accumulates on the surface of the soil as a layer of humus. This organic matter has

properties which influence the solubility of soil minerals.
2 Soil animals mix soil particles and help to aerate minerals.

It is very difficult to separate processes which are purely chemical from those which are biological in soil development. Usually biological processes have a profound influence on chemical processes. For example, an important process of soil formation and development is that of *chelation*. The word comes from the Greek word *chele* which means claw. The word aptly describes the process by which mineral ions are incorporated into the molecular structure of organic compounds. Elements like calcium, magnesium and iron are firmly attached in the molecular structure of organic compounds like humus acids.

If the soil has a thick layer of organic matter (humus) on its surface it means that any water percolating into the mineral material below will be charged with a large supply of organic compounds. Many of these compounds washed from the humus into the mineral soil below are capable of chelation. As the water percolates through the soil the organic compounds will take up mineral ions from the soil solids. In this way elements can be moved from the upper layers of the soil and washed down the soil profile. This washing process is termed *cheluviation*.

Cheluviation is responsible for the white, bleached layers which occur just below a layer of organic matter in some soil profiles (particularly in soils known as podzols). These bleached layers are extremely poor in nutrients as cheluviation is more efficient at removing elements than is the process of simple solution. Darker layers of redeposited organic matter and nutrients can be seen below these bleached horizons. These horizons are usually iron-rich, as iron is very easily moved by cheluviation (Figures 8 and 9).

As well as chelatory powers organic matter has the ability to produce hydrogen ions (which are important in hydrolysis). Thus the presence of organic matter on the surface of the soil greatly increases the movement of elements down through the soil profile.

Biological processes not only contribute to the movement of nutrients away from the surface of the soil but bacteria and fungi decompose the organic matter and release many of the nutrients that would otherwise be locked up in the organic compounds. These nutrients may then be available for use by plants. Also, the burrowing actions of animals like earthworms and ants may bring soil back nearer the surface and will thus bring nutrients which have

9

previously been washed down the soil profile back to the surface (Figure 10).

Finally it should be emphasized that while we began this section with reference to a knowledge of simple chemistry, most of the processes in the soil are very complex. It is impossible to separate biological, chemical, atmospheric and hydrological processes in a soil. Each factor interacts to produce a complex mixture of rock particles, organic matter, water and nutrients that constitute a soil.

Summary

Soil can be viewed as the equilibrium product of the reactions of such materials as rocks, glacial deposits and alluvium with their environmental conditions. Chemical reactions, such as solution, oxidation, hydrolysis and hydration, occur as a result of the presence of water and air in that environment. Moreover, physical actions, such as freezing, may result from cold environmental conditions. The presence of life means that biochemical reactions, such as chelation, can take place and also that organic matter occurs. A soil is formed as a result of all these reactions. The soil becomes organized into horizontal layers, or horizons, as a result of leaching and of organic processes. Vegetation helps to offset leaching by the recycling of nutrients. Soil is thus a product of the soil parent material reacting to its environmental conditions through various chemical and biological processes taking place within the soil profile over time.

2

Soil components and soil properties

2.1 Soil material

What is soil made of? In order to understand how soil develops and to understand the inner workings of soil we must examine the separate components that make up soil. Also, in order to understand soil sufficiently to be able to manage it efficiently for agriculture we must understand how the soil components may react to different agricultural practices. Each component has particular properties and functions which influence how a soil behaves as a whole. We shall consider each component in turn: mineral matter, organic matter, water, air, biota (plants and animals) and nutrients.
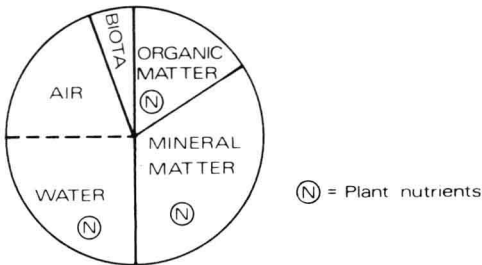

Figure 11   Relative proportions of soil components in an average agricultural loam

In sections 1.1 and 1.2 it was shown how the soil consists of a mineral 'skeleton' which is the weathered parent material. It was also shown that as the weathered material interacted with its environment it incorporated other components to form soil. In an average agricultural soil (a good, fertile loam) *mineral matter* from weathered rock and *organic matter* from plants and animals take up about half the volume of the soil and are thus the main soil components (Figure 11). *Air* and *water* take up the other half of the soil body. Air and water occupy the pore spaces between the mineral particles, and as water increases, with an input of rainfall, the amount of air decreases. As the soil dries (by evaporation and drainage) the amount of air in the pore spaces increases. Thus, in Figure 11 the boundary between air and water is drawn with a dotted line to indicate a fluctuating proportion. The

large *soil animals* and *plant roots* take up what would otherwise be air space. The *smaller biota* (bacteria, fungi and actinomycetes) are either present in the soil water or are distributed in the organic and mineral matter. *Nutrients* available to plants are found in the organic matter, in the soil water or in the mineral matter, but a large proportion is found in combination with compounds composed of both organic and mineral matter. These compounds are called the *clay–humus complexes* and they hold the biggest reserve of nutrients.

2.2 Soil mineral matter

Primary and secondary minerals

Soil minerals are derived from the minerals in the parent material by the weathering processes described in section 1.2. As soil formation is a continuous process the mineral matter can be conveniently divided into:

1 *Primary minerals* – those remaining unaltered from the original parent material.
2 *Secondary weathering products* – those produced by the weathering reactions.

While the primary minerals are those which were originally present in the soil parent material the secondary minerals are those which are produced in the soil. Thus the primary minerals remain in the soil during the soil-forming process and are those minerals which are relatively insoluble. They include such minerals as quartz, which are very resistant to weathering (see Figure 7). The secondary decomposition minerals include the products of the equilibrium reactions discussed in Chapter 1 and therefore include oxides and hydroxides of primary minerals which form as a result of exposure to air and water.

Clays

The exact composition of a clay depends upon the mineralogy of the parent material and the weather-
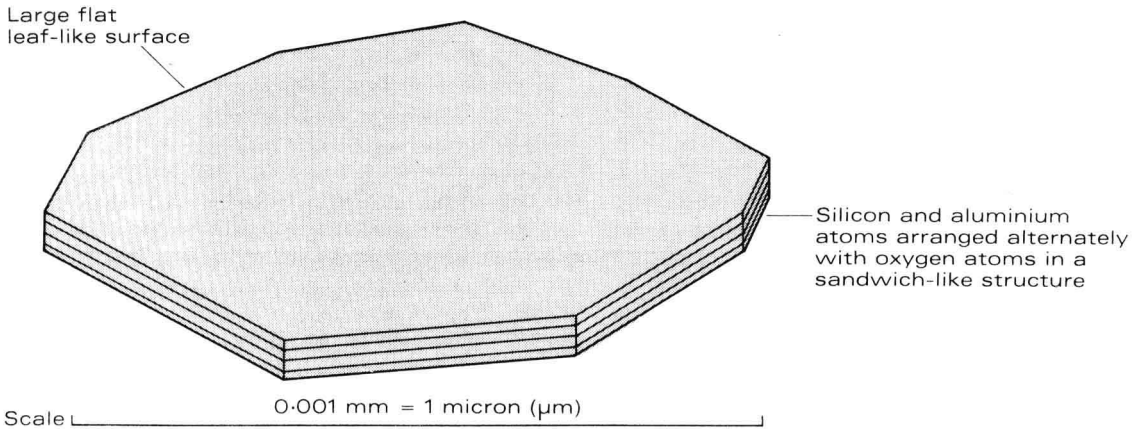
Figure 12 A clay micelle

ing environment. Silicate minerals, as was shown in Figure 6, may be prone to hydrolysis. One of the most important results of this reaction is the production of clays. Clays are minute particles composed of silicon (Si), aluminium (Al) and variable amounts of oxygen (O) and hydrogen (H) which are left after weathering reactions.

There are four main types of clay found in soils. Three, *kaolinite*, *montmorillonite* and *illite*, have a recognizable crystal structure. The fourth type, *allophane*, is non-crystalline and has no recognizable form. *Allophane* may include a number of different chemical types, but these are difficult to investigate because of the lack of structure; the terms the *Allophane Group* or the *Amorphous Clays* are often used to describe these clays. The first three types of clays mentioned have their atoms arranged in layers, like a sandwich. They belong to the group of silicate minerals termed *phyllosilicates* (*phyllo* = leaf-like) where sheets or leaves of atoms are laid down on top of one another. The basic clay structure is the *micelle* composed of several layers. The structure of a micelle is illustrated in Figure 12.

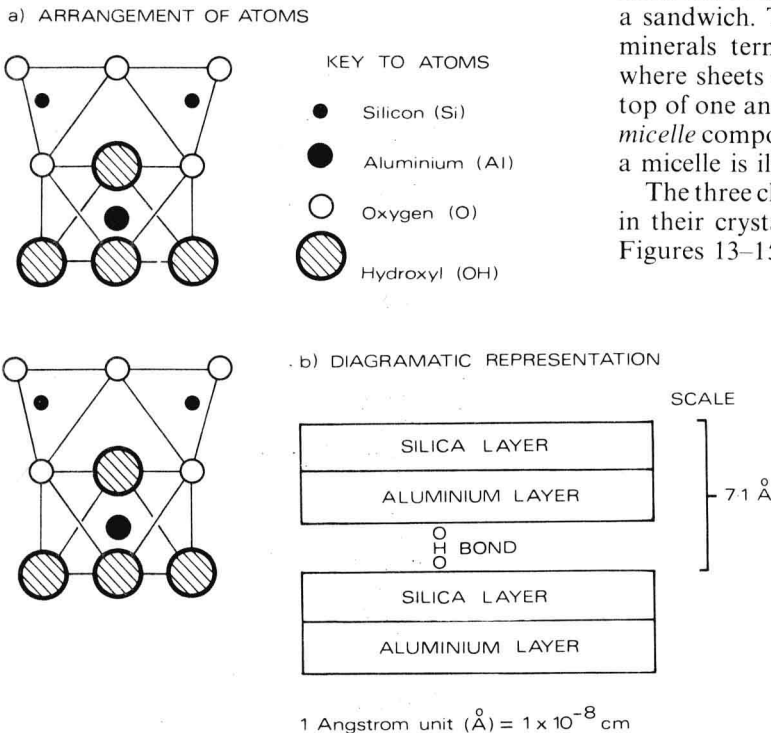The three clay types are recognized by differences in their crystal structure, and these are shown in Figures 13–15.

Figure 13 The structure of kaolinite

12